Toward a New Perspective on Problem Solving

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Educating students to become successful problem solvers has been a goal of education at least since Dewey. However, the kinds of problems students do in school to practice their problem-solving competence have little to do with the problems they will need to solve in everyday settings. We briefly critique traditional conceptions of problem solving, propose a different framework for theorizing problem solving, describe how innovative curriculum design was informed by this new conception, present a case study of problem solving in one of these curricula, and summarize research findings from our classrooms that support the new conception of problem solving.

L'un des buts de l'enseignement a été, du moins depuis Dewey, de montrer aux élèves à résoudre des problèmes. Toutefois, les problèmes que doivent résoudre les élèves à l'école ne ressemblent guère à ceux qu'ils devront régler dans leur vie quotidienne. Les auteurs présentent d'abord une brève critique des conceptions traditionnelles de la résolution de problèmes, puis proposent une conception nouvelle. Ils décrivent comment cette nouvelle conception les a guidés dans l'élaboration de programmes scolaires en sciences; ils présentent d'ailleurs une étude de cas afin de donner un exemple des compétences développées par les élèves dans ces programmes. Ils terminent leur article par une brève présentation des principaux résultats de plusieurs recherches ethnographiques sur l'apprentissage de la résolution de problèmes à l'école.

Preparing students for everyday life after school is one of education's primary goals. Learning to solve problems is a central concern in this endeavour. One underlying assumption has been that students will transfer not only the specific domain-related knowledge (such as mathematics) but also more general problem- and solution-related skills. Understanding how people do problems and teaching people ways to become better at doing problems have thus received much attention from educational psychologists, cognitive scientists, and educators. Models of self-regulated problem solving and learning abound (Butler & Winne, 1995; Carver & Scheier, 1990; Poissant, Poëllhuber, & Falardeau, 1994). Unfortunately, the models many authors provide are based on a limited class of problems not highly relevant to becoming a citizen able to function in a complex society. Numerous studies question the possibility for transfer of problem-solving skills from this class of problems to those that occur in everyday settings (Lave, 1988).

PROBLEM SOLVING IN LABORATORIES AND SCHOOLS

The tasks in traditional problem-solving literature are characterized by highly structured and well-defined knowledge domains. Mazes, the Tower of Hanoi, electrical circuits, river crossings, and radiation problems are standard tests of problem-solving behaviour (A. L. Brown, 1994; Lave, 1988). The advantages of using such tasks in psychological experiments are clear. The total number of solution paths is enumerable. There is an identifiable "best," "correct," or "right" solution which transforms the initial state to the final state. Any solution can be mapped to allow comparison between the solver's solution and the ideal solution. This comparison can be quantified as the difference between actual and ideal solutions (cf. Kanevsky & Rapagna, 1990). Disadvantages also arise: expert-novice studies associated with these kinds of models of problem solving often lead to characterizations of students in terms of deficits (as in "déficience dans le processus métacognitif" [Poissant et al., 1994, p. 33]), and misconceptions (Burbules & Linn, 1988) wherein responsibility for poor achievement is carried by the student rather than the teaching-learning system as a whole. J. S. Brown and Duguid (1992) argue that the "extremely influential dichotomy between novices and experts . . . fails to appreciate the way in which expertise is a fluid, social construction that is constantly subject to redefinition" (p. 172).

School problems posed by textbooks and teachers are typically of a similar type. Algorithmic approaches lead to correct solutions. The students' task is to find that set of algorithms which guarantees the solution and the reward in the form of a good grade. In school-like problems, the answers are already implicated, although they are withheld or concealed by the problem statement. What is offered as knowable (the answer) is prefigured in advance such that actual solution paths can be assessed against this ideal solution (Lynch, Livingston, & Garfinkel, 1983; Morrison, 1981). Students' tasks are to disclose what the texts (or problems) hide and to find their way through the maze of possible states. The most disconcerting research finding about school problem solving is that there is virtually no carryover to everyday problem solving: there exists a chasm between the problem-solving practices one needs to be successful in schools versus those needed in everyday life (Lave, 1992).

The following example from mathematics illustrates the maze-like character of school problems.[1] Finding the roots of a function such as $f(x) = x^2 - 5x + 6$ is a common problem at various grade levels. This problem can be framed and solved in many ways. Problem frames include factoring a polynomial, finding the roots of a polynomial, solving a word problem, or solving an equation. The solutions can also be framed in different ways, including numbers (2, 3), algebraic statements ($[x - 2] * [x - 3]$ or $[x - 2], [x - 3]$), a sentence in response to the question in the word problem, or a line on a graphing calculator. Among the possible solution paths, copying, guessing, and calculator-based solutions (Newton's method, graphing) are typically forbidden, and students' solutions and answer formats are compared against those *currently* favoured by the curriculum. Thus, when the current topic is "completing the square," only one of the different methods receives full credit; if the current topic is factoring or using quadratic equations, other solutions provide the standards against which students' work is compared. The students' problem is not to find *a* solution (as would be required in everyday life), but to find *the* solution legitimated by the teacher. This solution is not self-evident but has to be taken from other cues students receive from teachers. It is not surprising that students get lost in the maze of problems, solutions, and answer formats. Questions such as "Am I on the right track?," "Is this right so far?" and "I'm lost; what do I have to do?" are perfectly reasonable in such circumstances. They are also indicative of their tasks' character. Students find themselves in mazes and, rather than erring for too long, they ask for guidance from teachers who know the accepted path through the mazes; teachers hold Ariadne's thread.

We are not alone in comparing running mazes and school problem-solving. In her presidential address at an annual meeting of the American Educational Research Association, A. L. Brown (1994) explicitly linked behaviourist psychology and its experiments that asked children to run mazes (just like rats) with current schooling and testing practices.

FROM CLASSICAL TO SITUATED PROBLEMS AND SOLUTIONS

Traditional cognitive science (and artificial intelligence) has successfully applied linear models of problem solving to the solution of well-structured word problems in introductory physics or tasks such as the Tower of Hanoi.[2] Many cognitive scientists have adopted linear models such as that originally proposed by Dewey, and revised and popularized by George Polya in the late 1950s. However, most problems in everyday situations — whether in scientific laboratories, engineering firms, or supermarkets — are not linear. Numerous researchers have begun to realize that linear models fail to account for everyday problem solving because they are ill-suited to the dynamic and generally chaotic conditions of the workplace (Anderson, 1990; Greenbaum & Kyng, 1991; Heath & Luff, 1993; Lave, 1988; Schön, 1983; Suchman, 1987). This failure arises because linear and rationalistic problem-solving models were derived from highly structured sets of signals and cues, and in very limited domains that were well known by the solver. Scandinavian designers of computer tools for the workplace, who spent much time analyzing the competencies of skilled and experienced workers, pointed out the relationship between rationalistic (linear) approaches to problem solving and deskilling in the work force (Ehn, 1992; Greenbaum & Kyng, 1991). These analysts argue that deskilling is the result of (a) organizing workplace tasks based on inflexible algorithmic procedures, and (b) organizing workplaces in top-down fashion to legitimate algorithmic (pseudo) problem solving. Experienced teachers recognize that "deskilling" also occurs in many science and mathematics classrooms where students ask for “the right answer” rather than choosing from a panoply of problem frames, answers, and solution processes.

In response to rationalistic models’ failure to account for problem solving in everyday settings, the most common non-linear models of problem solving are cyclical (Starling, 1992). The models proposed by Carver and Scheier (1990) or Poissant et al. (1994), with their various feedback loops for self-regulation, belong to this class of problem-solving models. However, studies of everyday activity show that problem solving is not modelled well by such cyclical processes (Knorr-Cetina, 1981; Latour, 1992; Lave, 1988; Scribner, 1986; Sørensen & Levold, 1992). Furthermore, linear and cyclic problem-solving models based on individual mental processes do not model the situated, distributed, and embodied nature of knowing; they embody myths about the rationality of problem solving in everyday (normal or scientific) activity (J. S. Brown, Collins, & Duguid, 1989; diSessa, 1993; Hutchins, 1991; Lave, 1993; Pea, 1993; Scardamalia & Bereiter, 1994; Suchman & Trigg, 1993; Varela, Thompson, & Rosch, 1991; Winograd & Flores, 1986). Although traditional cognitive scientists recognize differences between everyday problem solving and the (pseudo) problem solving described by their models, they treat these differences as minor caveats that can be fixed by adding extra components to their models. Hutchins (1995) contends that such minor changes cannot remedy the problems of a modular approach to human cognition that “privileges abstract properties of isolated individual minds” (p. 354). For researchers who study problem solving by scientists and ordinary people in everyday life situations, these differences require complete abandonment of cyclical models.

PROBLEM SOLVING IN EVERYDAY LIFE

The following example from our own research illustrates the flexibility with which people frame and solve problems in everyday life; everyday problem solving is neither linear nor cyclical. Geena, an elementary teacher in one of our studies (McGinn, 1995), began to bake a batch of cookies as one of a set of tasks to find out about mathematics in teachers’ everyday lives. She read from a written recipe and added the ingredients to her bowl, mixing as she went. As she kneaded the ingredients together, she looked at the cookie dough with an expression of concern and remarked, “This seems awfully dry.” She turned back to the recipe for confirmation and explanation of this problem; she re-read the ingredient list (twice) and the directions, trying to puzzle out the problem. After a few minutes, she turned her focus from “I wonder why?” to “What am I going to use this for?” She looked around her kitchen, deep in thought, then announced:

> Well, it’s dry, it’s cookie. OK, this is what I’m going to do. I’m going to get my pan and I’m going to put. . . . I think I’ll cut up those apples [pointing to a bowl of apples at the edge of her countertop] ’cause I wanted to make some applesauce or something out of

them because they were going bad at school. So I think I'll put some apples in. Now should I put this on the bottom? Or maybe I'll do a double layer. I'll put some on the bottom and then I'll put some apples and then I'll put some of this on the top.

She proceeded in this fashion to create delicious apple squares.

This episode shows creativity, flexibility (she abandons the original problem), reorganization (she reframes the affordances of the environment), and a successful resolution. It shows the flexibility with which people frame their problems in everyday out-of-school situations. There is ample evidence that such problem solving seldom occurs in schools. More importantly, there is evidence that adults who are efficient problem solvers in everyday life revert to inflexible problem-solving algorithms on school-like problems (see, for example, Lave, 1988). Framing problems and enacting plans are central to problem solving in everyday situations.

Framing problems. In everyday situations, it is often unclear what the problem is: problems change, problems are sometimes preceded by solutions, and problems are abandoned in light of new developments (Cohen, March, & Olsen, 1979; Lave, 1988; Sørensen & Levold, 1992). The case of Geena shows some interesting dimensions of problem solving. Her initial problem was to bake a batch of cookies. At some point, she decided that the dough was not suited for baking cookies, a decision that already demanded a lot of experience not available to most novice or inexperienced cooks. She checked a few of her steps and measurements against the recipe (although it was not entirely clear if she went through the elaborate checking procedure as a result of the researcher's presence) and then decided to change the problem to make apple squares instead. However, this new problem arose from Geena's interaction with her environment such that the apples which at first were irrelevant to the problem (i.e., they would not have entered the situation definition as proposed by Poissant et al. [1994]) became a major factor in her resolution. Whereas the squares were a triple success — her co-workers found them delicious, their history made for a good laugh, and they made use of some overripe apples — Geena would have failed in most traditional school situations (home economics or mathematics), because she did not produce the cookies originally planned.

Geena's problem solving was entirely consistent with that found in assessments of successful engineering firms. Here, there are "disorderly problem-solving negotiations, in which different kinds of knowledge are contraposed and checked, and where the outcome also depends on the persuasive abilities of the engineers involved. . . . Consequently, what counts as relevant expertise and equipment is rather open" (Sørensen & Levold, 1992, p. 27). To frame and solve such problems, theoretical knowledge is almost never sufficient to make things work. Although situated, tacit, and practical knowledge built up through experience are key ingredients to success (Faulkner, 1994; Schön, 1983), they cannot guarantee success: "Neither tacit nor formal knowledge permits [photocopier] technicians to predict success in all cases; a working machine is the only real demonstration that one's knowledge was sufficient" (Orr, 1990, p. 170). To help clarify what is a problem, even highly trained economists, scientists, or technicians use stories instead of formal analysis (Bruner, 1986; Orr, 1990). For example, photocopier technicians, in their search for inspiration to deal with ill-structured problem situations, tell stories; "the hardest part of diagnosis is making sense out of a fundamentally ambiguous set of facts, and this is done through a narrative process to produce a coherent account" (Orr, 1990, p. 186).

Plans. In everyday life, plans are not as determinate as they appear in self-regulated problem-solving models (Carver & Scheier, 1990; Poissant et al., 1994). Rather, plans are merely rough guides that never uniquely determine future actions (Chapman, 1991; Suchman, 1987). Our example of Geena shows that her original plan (the recipe) was not sufficient to guarantee the cookies she had set out to bake. But she was flexible enough to modify her goal. Rather than making her new plan as explicit as the recipe, she continued, based on her situated knowledge of baking, to produce apple squares. The structure of the activity "Geena-baking-cookies-in-her-kitchen" arose from the interaction of Geena and the setting. In the same vein, a recent television documentary about the repair of the Hubble Space Telescope pointed out that despite extensive preparations (more than 1000 hours), astronauts knew there were "millions" of things that could go wrong once they were actually doing the repairs. What made the astronauts' actions so special was that they situationally resolved the contingent (unforeseen) problems that materialized in the course of their mission. Similarly, the extensive manuals photocopier technicians have as resources for doing their work are frequently insufficient to return broken photocopiers to an operational state (Orr, 1990). Thus, even in paradigm cases of planning, solution-related actions are inherently unspecifiable in advance. Furthermore, planning and executing plans are presented as essential components in most models of problem-solving behaviour (e.g., Poissant et al., 1994). In real-life problems, planning is often made unnecessary by providing problem solvers with appropriate technologies (Pea, 1993) or by changing structures of the setting in ways that unload thinking into the environment (Kirsh, 1995).

Our own examples and those from the literature show that problem solving is much more complex than cyclical problem-solving models suggest: solutions may precede problems, theoretical and practical knowledge is insufficient to frame problems, plans are not determinants of actions, and so forth. The technical rationality embedded in cyclical models appears to lead to the inflexible problem solving against which we would like to guard. We therefore question the practice of teaching students to solve problems according to models inappropriate for dealing with everyday situations, especially in light of educational goals to develop knowledge usable across contexts. We propose a different direction for planning instruction. Rather than basing curriculum design on problem-solving models of limited applicability, we base our designing on the findings of problem solving in out-of-school situations.

OPEN INQUIRY: REALISTIC PROBLEM SOLVING IN SCHOOLS

New perspectives, like new theories, should be not only plausible and intelligible but fruitful, in that they suggest new ways of designing instruction. Thus, new perspectives have to show new avenues for understanding learning or teaching, and to provide frameworks for changing curriculum. We have used the foregoing findings of problem solving in the workplace and other everyday settings to design new learning environments dubbed “open-inquiry” and “open-design” environments. Our designs of alternative problem-solving environments in schools have also built on students’ complaints that schools or universities do not prepare them for the complexities of everyday life (for example, for teaching) and parallel complaints from employers of recent graduates. What kinds of tasks let students engage in problem solving of realistic complexity? So far, we and our collaborating teacher colleagues have designed learning environments in which elementary students designed and built models of bridges and complex machines (Roth, 1996); middle-school students developed research agendas to investigate real biomes (Roth & Bowen, 1995); and high school students designed solar-powered water heaters (Roth, MacFarlane, & Nicholson, 1992), experiments on complex motion phenomena (Roth, 1993), or a curriculum on electricity for younger children (Roth, 1995). As students pursued their goals, they learned a lot of science and mathematics, more, in fact, than the curriculum prescribed. More importantly, they learned to structure their environment to achieve the (sometimes emergent) goals they set for themselves.

A CASE STUDY OF PROBLEM SOLVING DURING OPEN INQUIRY

Jamie and Miles were two Grade 8 students involved in open-inquiry science. Their teacher had asked his students to stake out a 40-m^2 research site and to spend 10 weeks finding out as much as they could about biotic and abiotic aspects of the site. They had complete freedom to choose how they would frame their research questions, design investigations, collect data, and present their results (e.g., data table, graph, or maps). During their investigations, their teacher assisted them on a just-in-time and as-needed basis. The core requirement for students was that they make convincing cases for their research questions, design, and results; they had to defend their work in small groups with students from other research teams.

Based on their previous research at the site and their emerging questions, Jamie and Miles decided to investigate whether there was a relationship between the abiotic variable of light intensity and the biotic variables of plant density and plant growth. In their field site, they selected may apples as the plant to investigate.

What is an appropriate average light intensity? At the end of their previous investigation, they had established some baseline data on the density of may apples and the average plant height in three locations of their research site. Now, they returned to measure the growth and light intensity, and to update their earlier plant density measurements. Jamie wanted to sample the light intensity once in each of three 1-m^2 plots. Miles noticed that light was unevenly distributed across the plots, and raised this concern.

1. Miles: But the thing is, that light, half of our area doesn't even have any light.
2. Jamie: Well, we can measure in that area [points to centre of one plot].
3. Miles: Yea, but in order to get a fair comparison you have to measure every single little wee bit in the area. What do you think we should do?
4. Jamie: Well, let's do the four corners of it, and the middle, like do 5 spots.

Miles had formulated a problem: If they followed Jamie's plan, they would bias the light intensity measurement (line 1). However, Miles realized that his own suggestion for dealing with this problem, "to measure every single little wee bit," was unreasonable. They did not have the means to measure the total amount of light falling on each 1-m^2 plot. Jamie responded with the proposition that they take five measurements, one in each corner and one in the middle. They would average the five readings as a measure of the light falling onto each area. Here, the solution to the problem Miles had framed arose from the interaction of the two students. Miles' own solution would have been too labor intensive with the means they had at hand; Jamie's proposal constituted a compromise solution to the problem they had framed. Here, Jamie and Miles not only framed the problem and negotiated and arrived at a solution, but they also evaluated the solution as appropriate for their current purposes.

What is an appropriate protocol for measuring light intensity? Jamie and Miles continued to frame and resolve problems as they worked toward their investigative goals. For example, immediately after the previous episode, another problem emerged from their interaction. Jamie had repeatedly measured the light intensity at ground level in each of the 1-m^2 plots. As he took another measurement, a may apple plant shaded his light meter. He reported this measurement to Miles, the current recorder, but emphasized that the light meter had been shaded by the plant.

5. Jamie: In this corner it [the light meter] is kind of shaded by the plant, 300 [foot candles] . . . got that? [Measures light intensity at ground level.] This [light meter] is *really* shaded by the plant.
6. Miles: Put it above the plant.
7. Jamie: I guess. Another 500, and now the middle [measures at ground level, then moves meter above the plant], to get a better reading, 425.

In this episode, Miles suggested measuring light intensity at a height above the leaves of the largest plant. Initially, Jamie did not react. But when he moved to the next sampling site, he framed the same problem again. He recognized the interference of leaves as a recurrent issue and moved the tool as Miles had suggested. While taking yet another measurement, he remarked, “OK, I didn’t think of the plant height, I have to do it again, now it’s 1100 [foot candles], OK.” From this moment on, Jamie’s measurement technique was entrenched. He held the light meter at the same height whether there was a plant or not; and he repeated all previous measurements.

Is 2000 footcandles a meaningful measurement? Unlike in traditional laboratory exercises where students conduct investigations without understanding (a) the reasons for collecting particular data, (b) the quality of the data they collect, or (c) the problems underlying the measuring process, students in the open-inquiry learning environment continually problematize these issues (Roth, 1994). The following transcript illustrates this ongoing concern for understanding. Here, Miles problematized a particular elevated light intensity (lines 8, 10).

8. Miles: 910, so that one has the most.
9. Jamie: That’s ’cause of the 2000.
10. Miles: Because of the big 2000. [pensive] Doesn’t make any sense!
11. Jamie: It does, though. This one looks the darkest, and that’s what you had measured.
12. Miles: Is that area [points] lighter than that area [points]?
13. Jamie: Yeah. Look how light it is in the middle there and then on the sides.

After Miles framed the problem of the high measurement, the two collaboratively assessed the situation. Jamie was able to allay Miles’ concerns by pointing out that the area with the high light intensity was in fact the brightest (lines 11, 13). Miles’ questions directed their inquiry into the meaningfulness of 910 foot candles as an average measurement of light intensity.

What is the average plant growth when there are additional plants? In the end, Miles and Jamie had collected all the data they needed for their purposes. They constructed a table into which they transferred their data (Table 1). Whereas they had little difficulty calculating the average density of may apples in their plots, they turned average growth rates into a problem. Since their baseline measurements, the number of plants had increased in one of their plots. Simultaneously, the average height of the plants in this plot had decreased. They immediately framed this as a problem: There was negative growth! In the course of their discussion, Miles suggested looking at total plant height rather than average height. He suggested that this way they could assess how much additional height there was over their baseline measurements. Again, they framed their problem and constructed a suitable solution.

As part of the larger study, we also wanted to find out if there were differences between students’ problem solving when they framed problems on their

TABLE 1

Miles and Jamie's Data Table to Represent Plant Growth

		Height of Plant (cm)	
Day	*Plant #*	*Area 1*	*Area 2*
1	1	17	19
1	2	20	22
1	3	23	16
2	1	18	20
2	2	21	23
2	3	24	17
2	4		5
2	5		12

own versus when the problems were constructed by the teacher. In one of the tests we conducted to answer this question, we used Jamie and Miles' problem, turned it into a story, and added their data. We then distributed this "problem" in three classes of Grade 8 students engaged in similar fieldwork. We found that 38% of the students calculated the total growth of all plants in each zone to determine average growth per plant. A partially mathematical approach was used by 29% of the students: these students first compared growth rates of the existing plants (which were equal) and then reasoned that Area 2 showed more growth because of the added plants. Some students (19%) disregarded the new plants and indicated that growth rates in the two areas were the same. The remaining 14% of the students responded with answers which did not compare growth rates. Whereas our videotapes and students' worksheets underscored the sophistication in students' approaches to *our* word problems, we also had to acknowledge that these word problems severely constrained the flexibility with which the same students framed and solved problems as part of their fieldwork (cf. Roth & Bowen, 1993).

Assessment of problem solving. Our analysis of these and many other episodes from the fieldwork of Jamie, Miles, and their peers led us to the following conclusions. Problems the students recognized as real emerged from their ongoing activity as they pursued previously set goals. In the course of pursing these goals, conflicts and dilemmas arose that sought solution. The students recognized these conflicts and dilemmas as authentic. Determining an appropriate and defensible average light intensity, height for holding the light meter, or magnitude of measurements were dilemmas that engaged students, who owned the dilemmas and their resolution. Jamie and Miles averaged five measurements in each plot because they considered this a fairer comparison across plots; they changed their measurement protocol in terms of how high to hold the light meter, and repeated all previous measurements because they were concerned with the shading; and they assessed the feasibility of a high light intensity because they wanted to understand. In contrast, whenever we presented word problems, students' work changed, even though these problems arose from the contexts of students' inquiries. Jamie and Miles' science and mathematics learning as part of their fieldwork was situated and dilemma-driven; they "'mucked about' with quantitative dilemmas" (Lave, 1992, p. 80). Their own problem setting and solution finding involved the total available resources of the activity: students, tools, the setting for their investigations, and their goals. Students saw *our* word problems as puzzles that hid the kind of contextual information to which they had access during fieldwork. As a result, the problem-solving competencies we observed with our word problems were lower than those we observed during students' fieldwork.

SUMMARY OF FINDINGS

Our studies of problem solving in these environments revealed a number of striking and, to traditionalists, unexpected findings. First, students from Grades 4 through 12 learned not only to cope with ill-structured and ill-defined problem-solving tasks, but to exploit the associated interpretive flexibility of the problems. Furthermore, they became very proficient in material-related (using instruments, computers, statistics programs, and related tools) and symbolic scientific practices (language, graphing, other mathematizations). With time, they built research agendas and developed experiments that simultaneously investigated multiple dependent and multiple independent variables (Roth & Bowen, 1993; Roth & Roychoudhury, 1993). We observed that many student experiments began with everyday out-of-school experiences, and many in-school investigations had direct applications to out-of-school life. Through their problem-solving activities, these students partially overcame the typical gap between in-school and out-of-school activities. We concluded that, for our students,

> well-structured problems did not exist. What was to become a problem always arose from the interplay between the participants, the activity, and the context. These problems were unpredictable both in their form and [in] their content. Our participants had to frame these problems on their own before they could resolve them, that is, they had to impose their own meaning to structure the phenomena. . . . From a constructivist view, such problematic situations provide favorable conditions for learning, because the problem solver is facing conditions for which no known procedures are available. (Roth, 1994, p. 216)

Our case studies of problem solving in open-inquiry environments showed that much like the studies on everyday problem solving cited earlier (Lave, 1988; McGinn, 1995; Sørensen & Levold, 1993; Suchman, 1987), classical cyclical models such as that of Poissant et al. (1994) did not account for our students' problem- and solution-related activities. Rather than running mazes, our students engaged in problem solving where (a) goals were endogenous to the constitution of problems, (b) problems were owned by students rather than given in normative, decontextualized form by external agents, and (c) solution processes were meaningful and purposeful, constituting truly constructivist activities (Roth, 1994).

CONCLUSIONS

Given that students are to engage in problem solving, educators need to make decisions about the kinds of problems students ought to solve. Educators therefore need to ask whether they want to educate maze runners, or to prepare citizens able to cope with the complexities of everyday life; that is, educators face moral questions about educational aims (Pea, 1993). Linear and cyclic problem-solving models lead people to algorithmic procedures rather than to the dynamic and adaptive actions necessary in a generally chaotic world. Our past experience with students and employers, who felt that school and university instruction did not prepare graduates for the challenges of everyday life, clearly affected our decision to include open-ended problem solving in ill-structured domains as a significant portion of our curriculum. The discontinuity between in-school and out-of-school problem solving can only be overcome when students engage in schools in problem solving resembling that required out of schools: "Part of knowing how to learn and solve complex problems involves knowing how to create and exploit social networks and the expertise of others, and to deftly use the features of the physical and media environments to one's advantage" (Pea, 1993, p. 75). Our studies of students' problem solving on ill-structured tasks support such assumptions. Thus, the design of problem-solving tasks should ultimately be driven by the potential benefits for students rather than by ease of information transmission and task evaluation. The merit of designing tasks on the basis of models that account for only a very restricted and simple class of problems is highly questionable. Educators need curricular tasks that provide students with practice in the flexible problem framing and solving demanded by complex everyday problems.

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NOTES

[1] Our present critique is concerned only with the question of "Which answer do students provide?" rather than with the (for some readers, more pressing) question of "Why do we teach factoring squares?"

[2] Recent work in both cognitive science and artificial intelligence has begun to recognize that intelligent problem solving and cognition more generally have an emergent character and arise from the interaction of agents and their settings (e.g., Agre, 1995; Chapman, 1991; Hutchins, 1995; Kirsh, 1995).

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